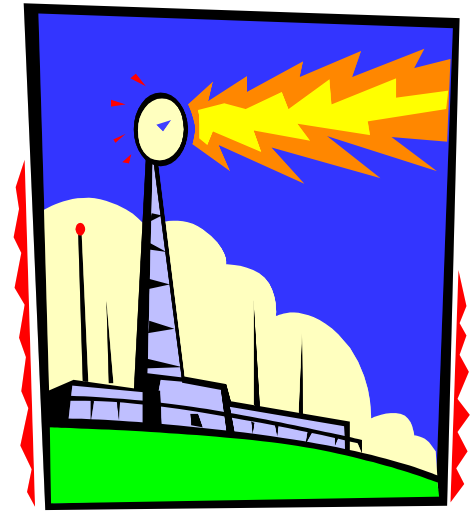
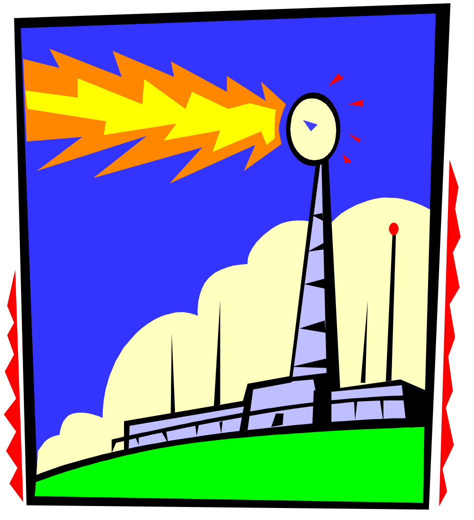
ILC RF Sources

Fermilab AAC Review of SMTF

May 10th, 2005





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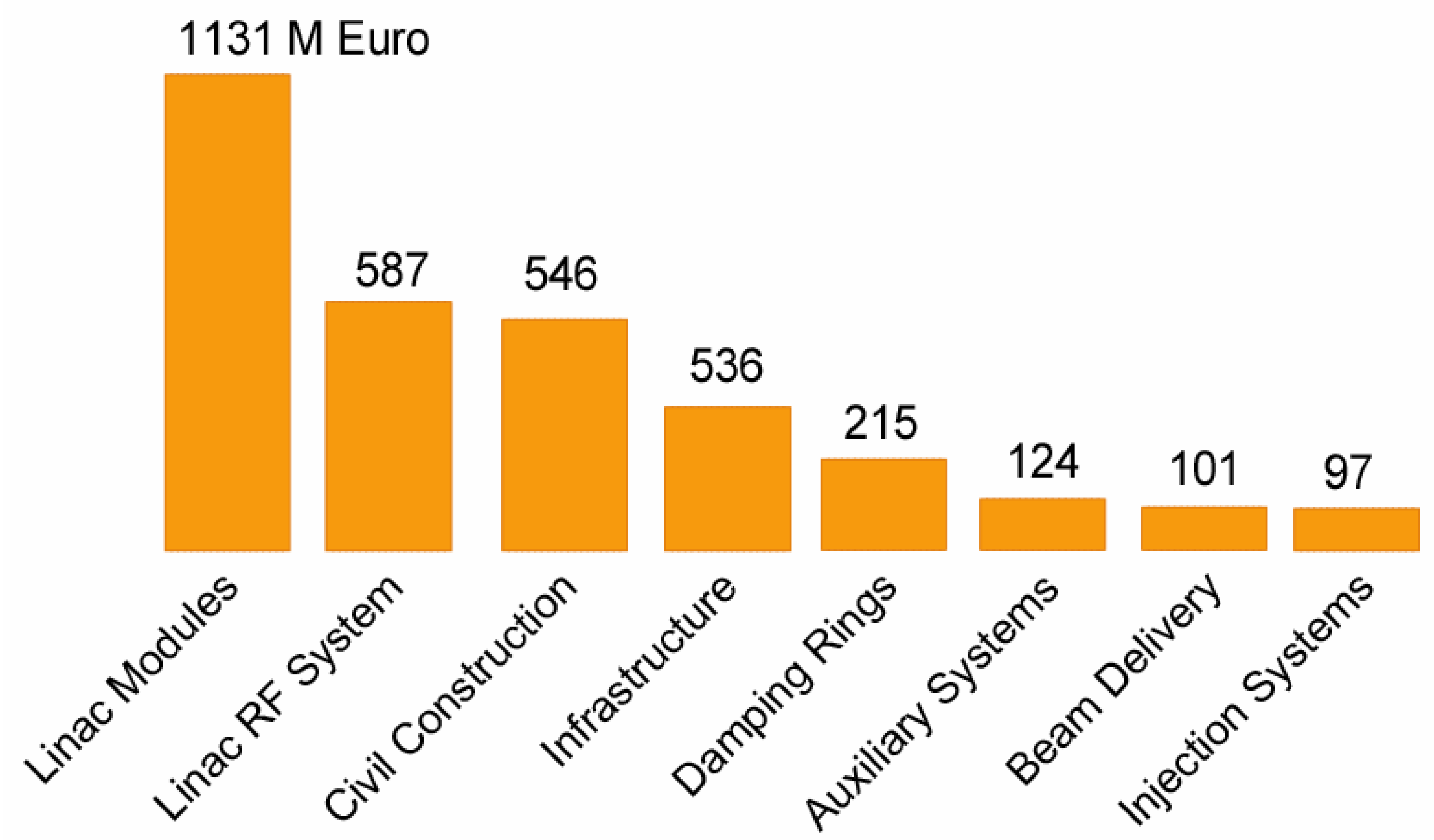
SLAC

ILC RF Sources Overview

- For the cold ILC technology, a little power goes a long way.
  - A 5 MW klystron can power 16 cavities (two cryomodules) to 25 MV/m for the ILC design Qext of ~ 3e6.
- For testing, commercial 5 MW klystrons are available as are lab or commercial built modulators.
  - Cost of a 5 MW rf station including controls ~ 1.5 M$
- For ILC, higher power, lower cost, more reliable modulators and klystrons are being developed.
  - However, do not want complicate cavity test program by using prototype ILC sources, so source development will proceed in parallel, at least initially.

TESLA TDR Cost Estimates
(RF Sources ~ 1/3 Linac Cost)



Modulators for ILC

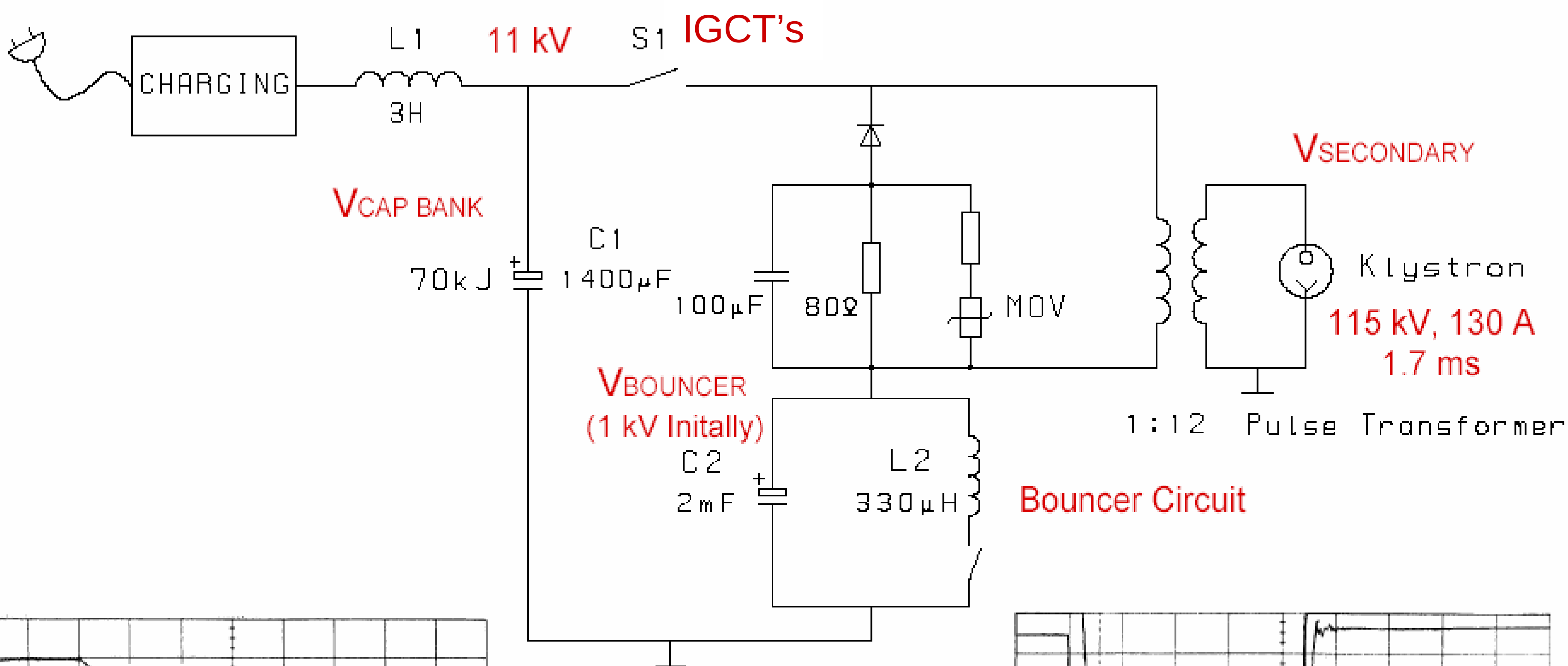
Requirements

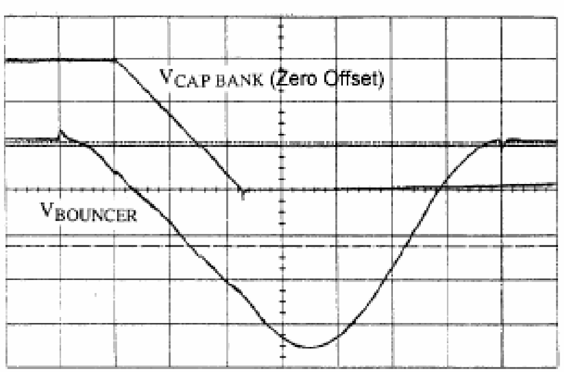
RF Pulse Length	1.37 ms
Modulator Pulse Length	1.7 ms max
Modulator Rise/Fall Time	0.2 ms max
Klystron Gun Voltage	120 kV max
Klystron Gun Current @120kV	140 A max
Pulse Flatness	+/- 0.5%
Total Energy per Pulse	25 kJ
Repetition Rate	5 Hz
Modulator Efficiency	85%
AC Power per RF Station	120 kW
Number of Modulators	560

- ILC baseline choice is the FNAL/DESY/PPT 'Pulse Transformer' modulator
- SLAC is evaluating alternative designs (SNS HVCM, DTI Series Switch and Marx Generator)

ILC Baseline Modulator

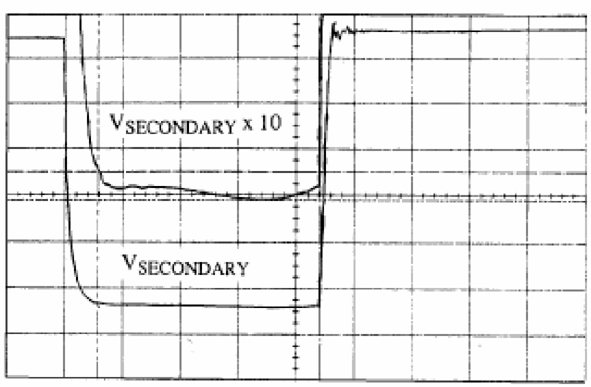
FNAL Design in Which a Bouncer Circuit Offsets the Voltage Droop (19%) During Discharge of a Capacitor Bank





500 V/div

1 ms/div



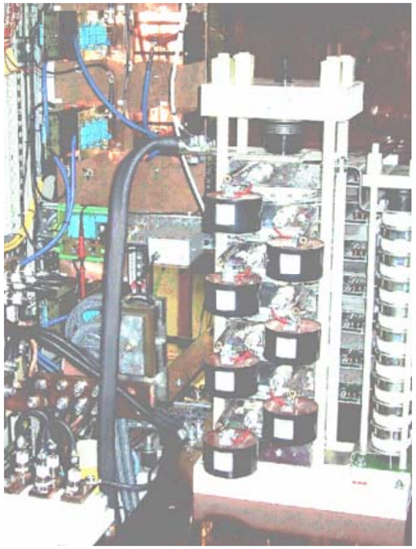
2 kV/div (top)
20 kV/div (bottom)

0.5 ms/div

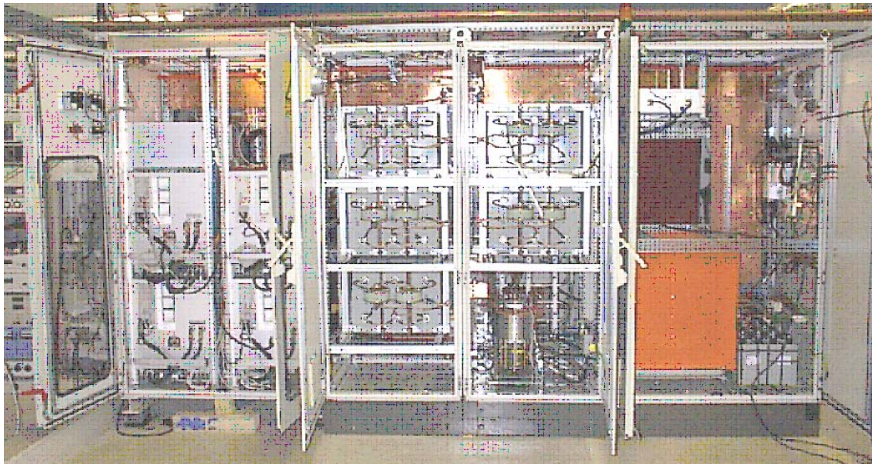
Pulse Transformer Modulator Status

- 10 units have been built, 3 by FNAL and 7 by industry (PPT with components from ABB, FUG, Poynting)
- 8 modulators are in operation
- 10 years operation experience
- Work towards a more cost efficient and compact design has started
- FNAL will build two more for SMTF with 4.5 ms pulse capability, which is required for the Proton Driver.

IGCT Stack



HVPS and Pulse Forming Unit



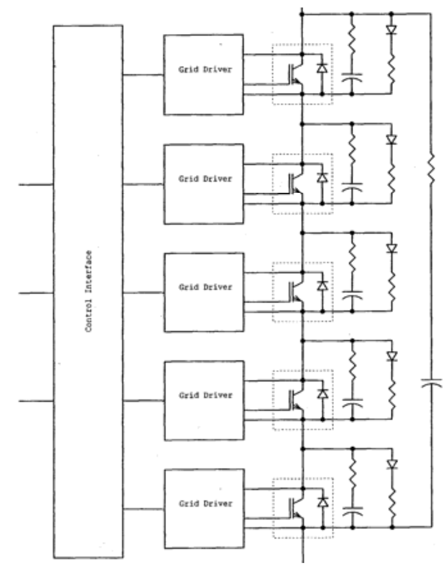
Proposed Changes to Original FNAL Modulator Design

- New Switch Technology:
  - Using Only New Higher Voltage Devices
    - 50% reduction in cost and physical size
- New Capacitor Technology:
  - Use New High Energy Density Capacitors for Main Capacitor Bank
    - Self Healing Polypropylene / "HAZY" Capacitors
    - Low Current Crowbar allows the use of these capacitors
- Modulator Controls:
  - Using Surface Mount Components Leads to Fewer Interconnects
    - 25 % Reduction in Parts Cost / 50 % Reduction in Labor
  - Simplify / Reduce Number Of Interlocks
    - All trips should be meaningful

New Switch Design Provided by SLAC

Two parallel IGBT's stack similar to that above
- Light triggered
- Water cooled
- Snubbers not shown

- 10 kV Nominal operation
- >2.5 Voltage safety factor
- 1700 Amp pulsed current
- >2.4 Current safety factor
- 5.1 msec pulse @ 3 PPS
- IGBT's cycling life time $>10^9$ Pulses @ 99% confidence.
- Redundant pulse input control
- Detection and opening of switch in case of a single fault
- Snubbers design to prevent cascade failures during turn off



Switch Schematic
- Redundant drive
- Independent snubbers

Alternative ILC Modulators

SNS High Voltage Converter Modulator (HVCM)

RECTIFIER TRANSFORMER AND FILTERS

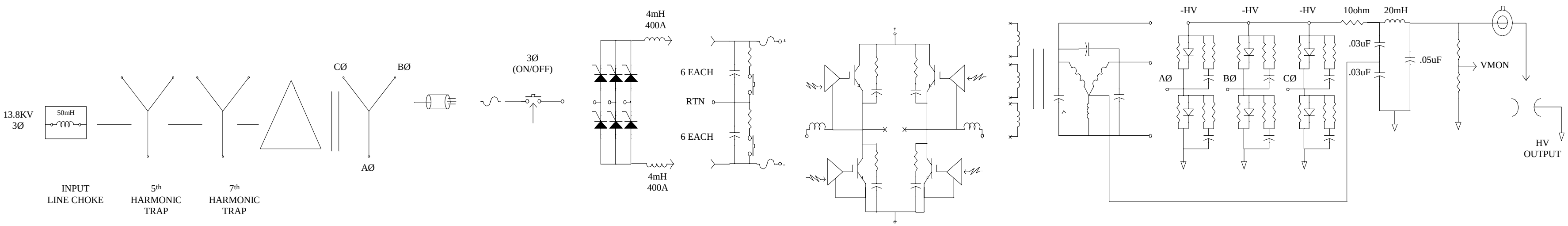
SCR REGULATOR

ENERGY STORAGE

SWITCHING

BOOST TRANS-FORMER

HV RECTIFIER AND FILTER NETWORK



RECTIFIER TRANSFORMER AND FILTERS

SCR REGULATOR

HVCM

EQUIPMENT CONTROL RACK

SLAC L-Band Test Facility

- Will receive a spare HVCM from SNS next month
- Buying 5 MW TH2104 tube from Thales (1 year delivery)
- Scrounging klystron parts from SDI/Anthrax/etc programs

SNS Modulator

FNAL 2095 Klystron

Series Switch Modulator
(Diversified Technologies, Inc.)

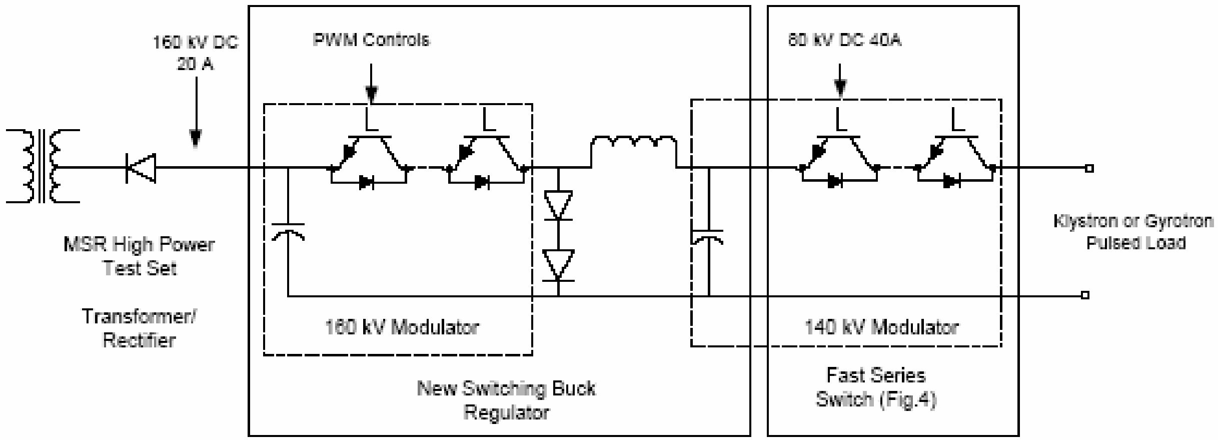


Figure 8. Modulator/Switching Buck Regulator Configuration

Diversified Technologies, Inc.

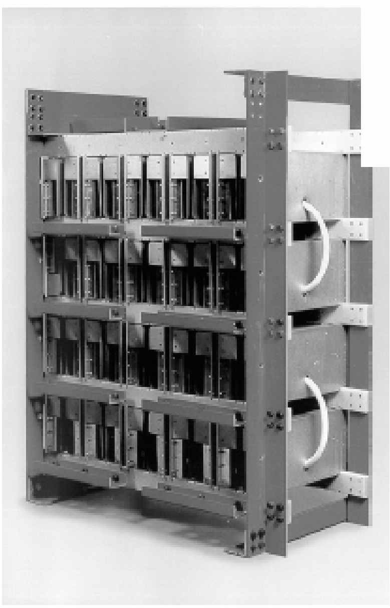


Figure 2. 140kV, 500A solid-state switch

- IGBT Series Switch
- 140kV, 500A switch shown at left in use at CPI
- As a Phase II SBIR, DTI will produce a 120 kV, 130 A version to be delivered to SLAC by the end of 2005

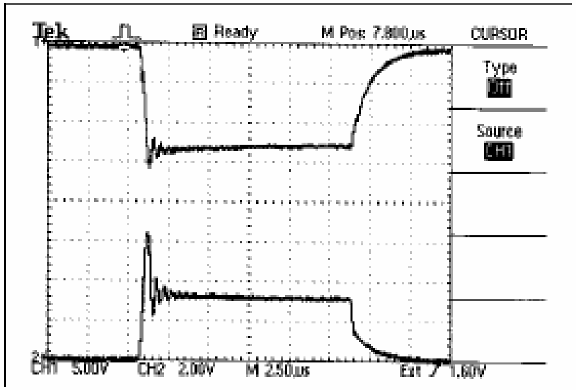
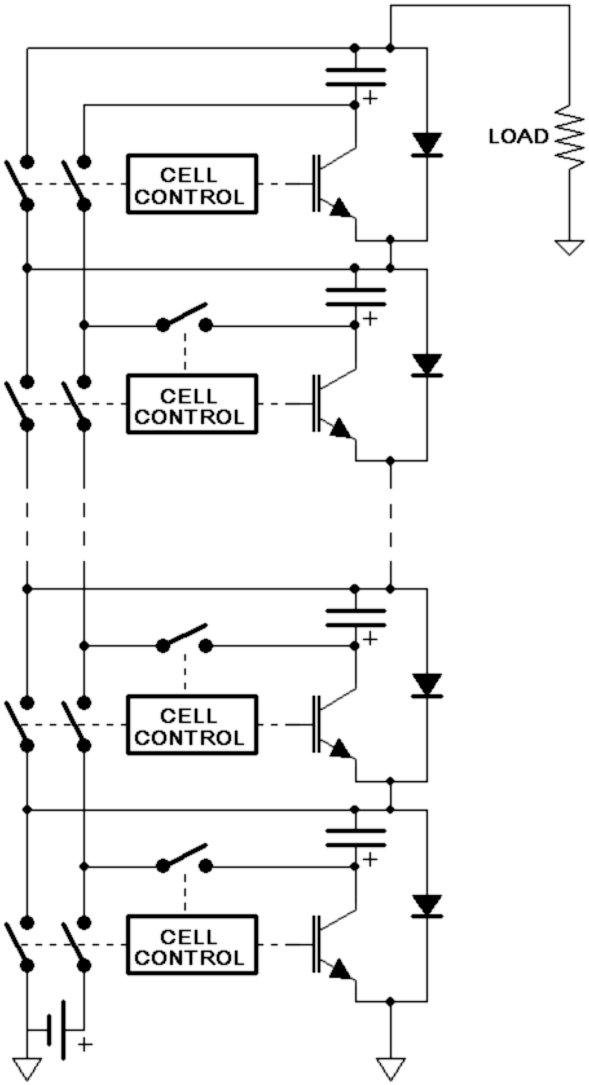
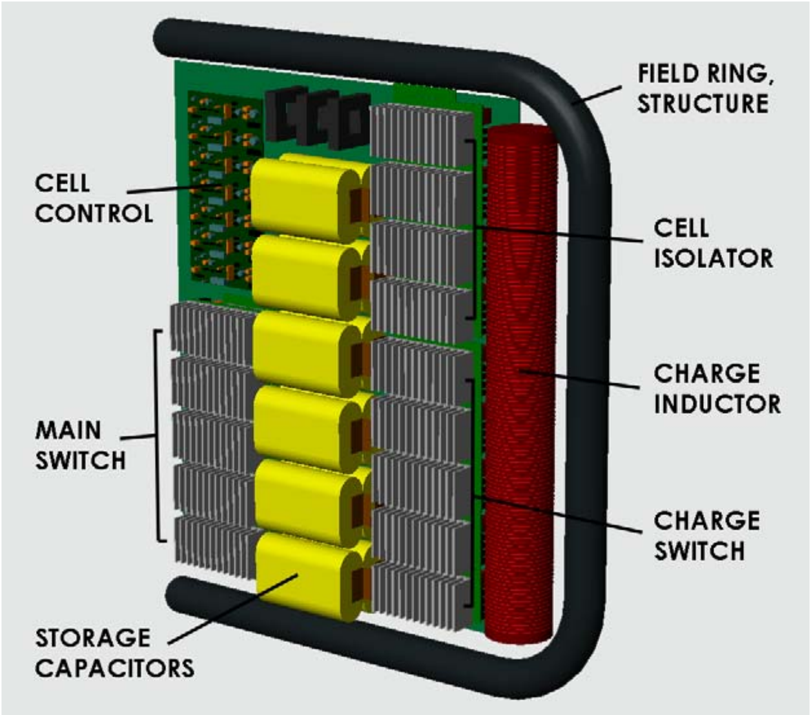


Figure 3: Test pulse (140 kV, 160 A, 13 µsec) of solid-state modulator. Upper trace is voltage at 63 kV/division. Lower trace is current at 100 A/division

SLAC Marx Generator Modulator



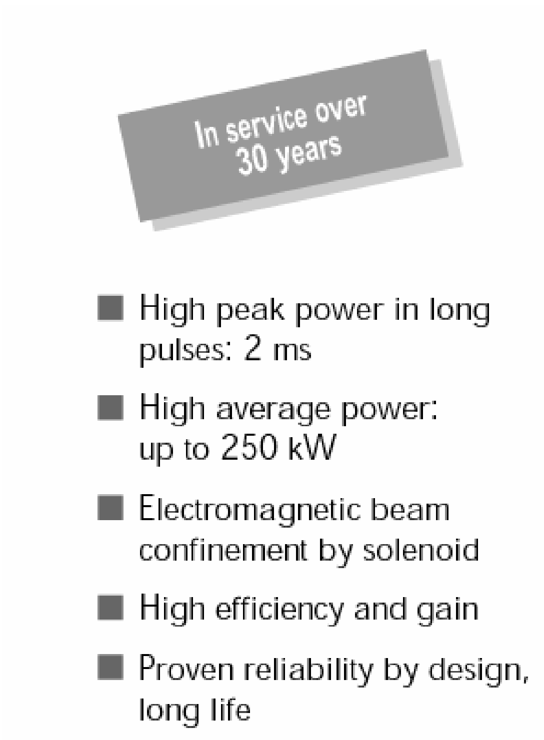


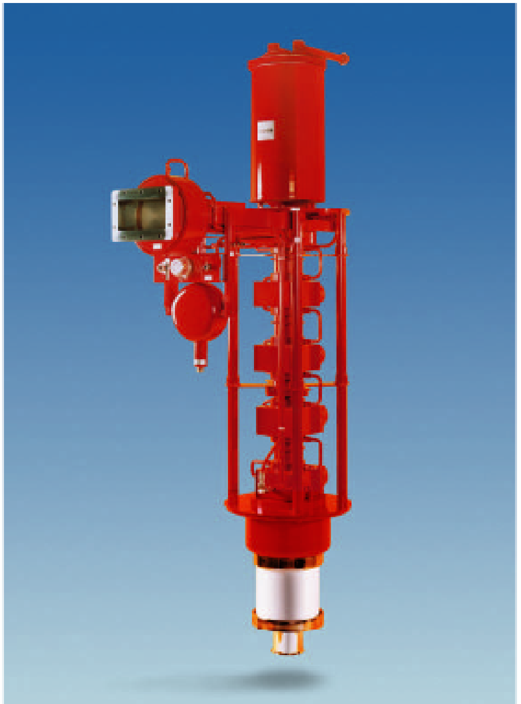
12 kV Marx Cell (1 of 24)

- IGBT switched
- No magnetic core
- Air cooled (no oil)
- Building prototype (2007)

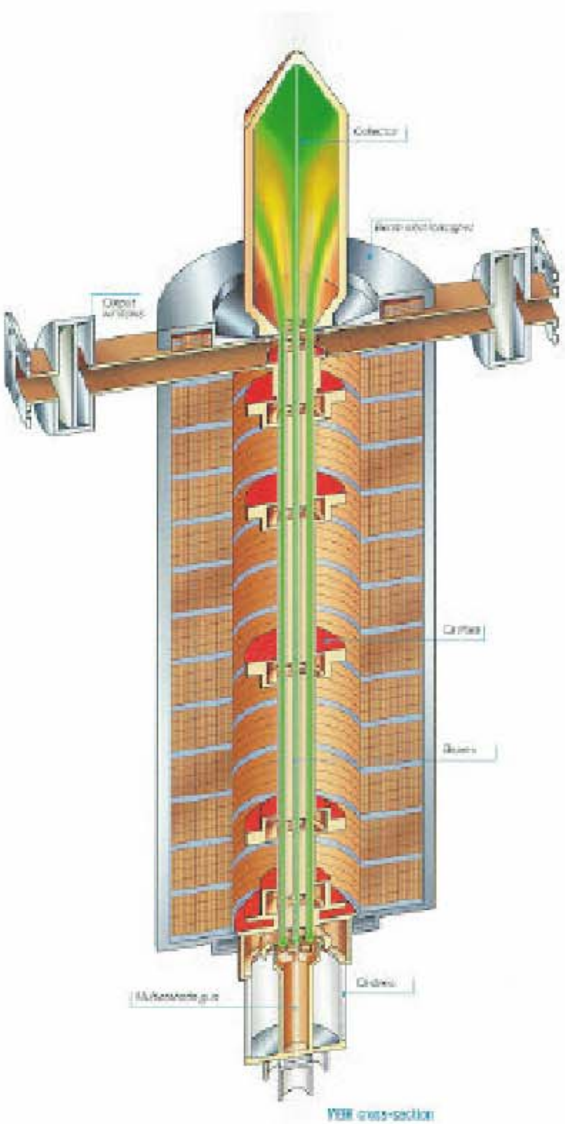
Klystrons

- The 1.3 GHz ‘workhorse’ tube for operation and testing at FNAL and DESY is the Thales 2104C single beam klystron – have one spare at FNAL for initial testing at SMTF.
- It produces 5 MW, 2 ms pulses at up to 10 Hz.
- Its 46% efficiency is low compared to that achievable (~ 70%) at lower perveance – it is not an ILC candidate.





ILC Klystron Development



GOAL

Reduce HV Requirements and Improve Efficiency (Lower Space Charge) with a Multiple Beam Klystron

Use Seven 19 A, 110 kV Beams to Produce 10 MW with a 70% Efficiency

Thales TH1801 MultiBeam Klystron

Spec's:
10 MW, 10 Hz, 1.5 ms with 4 kW Solenoid Power

First Tube Achieved 65% Efficiency at 1.5 ms, 5 Hz and Is Used in TTF

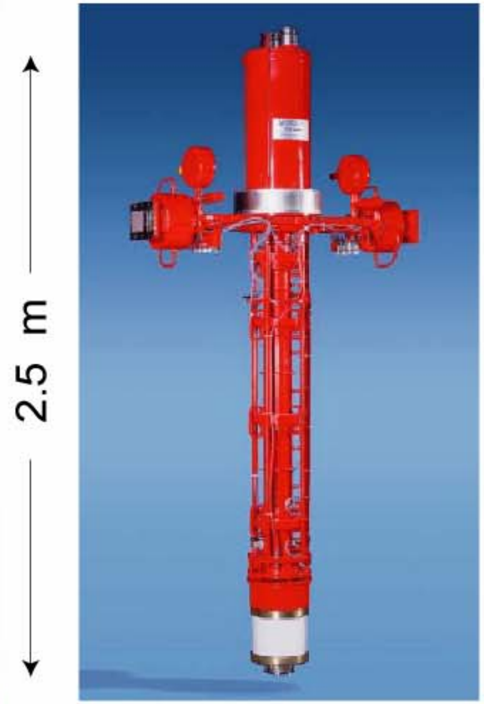
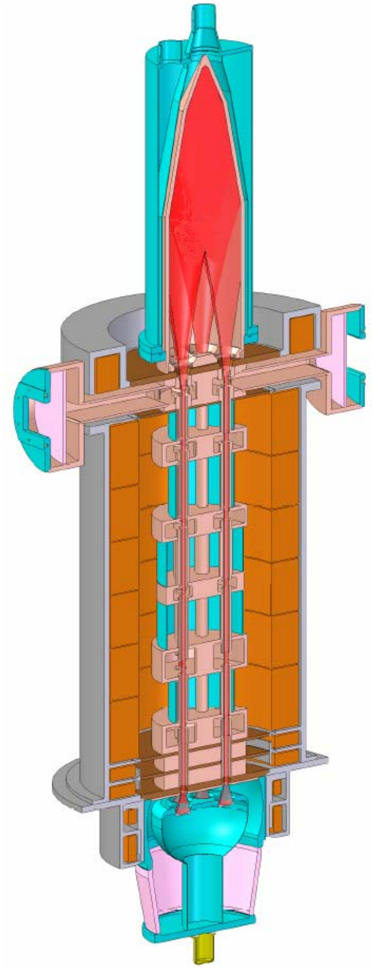


Photo of TH1801 Tube (top) and Cathode (bottom)

Other 10 MW Multi-Beam Klystrons Being Developed

TOSHIBA E3736
(Collaboration with KEK)



Features

- 6 beams
- Ring shaped cavities
- Cathode loading < 2.1 A/cm^2
- Expect ~ 100 khour cathode lifetime compared to ~ 40 khours for the Thales tube

VKL-8301

Features

- Six cathodes with six heater feed-throughs
  - can turn off individual cathodes
- Six cavities in each beam-line
  - three fundamental-mode with external tuners
  - one second-harmonic
  - two common HOM (input & output)
- Six isolated collectors
  - can measure intercepted current in each beam-line
  - one main collector water manifold
- Low cathode loading
  - Expect ~ 100 khour cathode lifetime

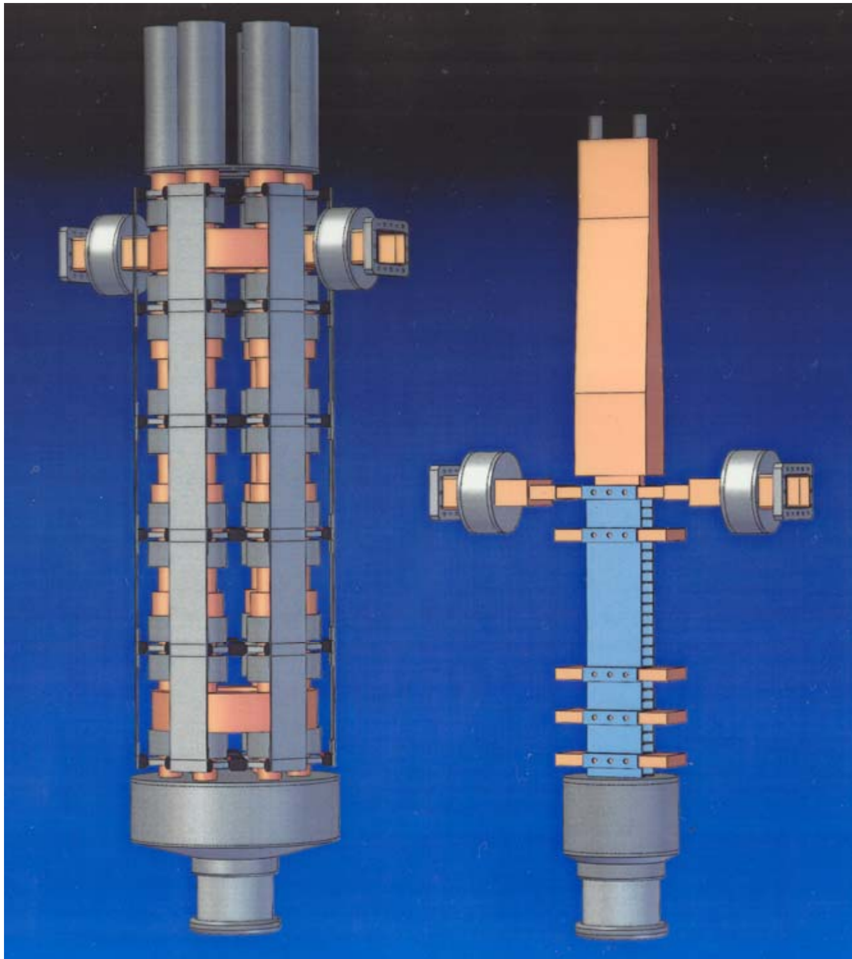
Klystron Status / Program

- DESY 10 MW Klystron Program
  - Three Thales tubes built, five more ordered – all 3 tubes developed gun arcing problems – two rebuilt to correct problem but not fully tested, the other has run for 18 khour at lower voltage (~ 95 kV).
  - One CPI tube built – achieved 10 MW at short pulse length, limited by CPI modulator - was accepted by DESY – may come to SLAC after testing at DESY.
  - One Toshiba tube built and under test – 10 MW, 1 ms achieved – longer pulses limited by modulator, which is being upgraded.
- SLAC Klystron Program
  - Developing 10 MW L-band Sheet-Beam Klystron.
  - If multi-beam program falters, consider lower perveance, single beam, 5 MW tube, possibly with PPM focusing.
  - Buy commercial 5 MW tubes as needed for 1.3 GHz NC structure and coupler program.
  - Possibly work with DESY and CPI on CPI 10 MW tube.

SLAC Sheet-Beam Klystron

- Exploring a sheet beam klystron as an alternate to the multi-beam tubes → significant cost reduction
  - High efficiency design using flat beams instead of 6 beamlets.
  - Smaller with simpler focusing, cavities, and cathodes.
  - Although intrinsically a 3-D design, programs exist to model it.
  - No experience with sheet beam tubes.
    - Building a W-band tube using external funding

Multi-beam tube   Sheet-beam tube



RF Source Summary

- For the 2005-2007 SMTF Program
  - FNAL building two Pulse Transformer Modulators with SLAC built switches.
  - Will use spare 5 MW commercial klystron (TH2104C at FNAL) for initial cryomodule operation. For reference,
    - Cost of a new 5 MW tube is ~ 400 k$.
    - Cost of a ‘limited warranty, ’ 10 MW, multi-beam tube is 800-900 k$.
- SLAC RF Sources Program
  - Proposing program of long-term baseline modulator and klystron testing.
  - Evaluating alternative modulator and klystrons designs.
  - Well positioned to provide sources for SMTF in the future.